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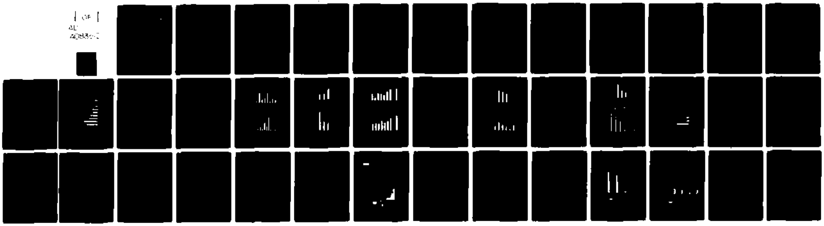

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16. Abstract

This report is the result of extensive research into the physical characteristics of channel design and the present aids to navigation of 32 prominent U.S. ports. The findings show trends in the interactions of the variables: width, length, depth, turn radius, aid configuration, aid spacing, flash rates and others for both day and night. These findings present a general analysis of what actually exists in the major U.S. shipping lanes.

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METRIC CONVERSION FACTORS

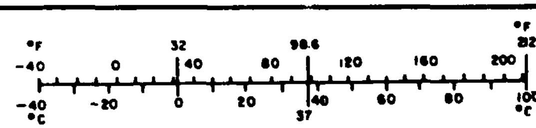
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Section 1

OVERVIEW

1.0 INTRODUCTION

The navigational safety of vessels in harbor waterways depends on many variables. The principal variable over which the U.S. Coast Guard exercises direct control is the provision of short range aids to navigation: buoys, beacons, lighthouses, daymarks, and range lights. Presently, there are few standards for the placement of aids to navigation. The present system of aids has primarily evolved over a period of many years as each USCG district office responded to requests for aids from local pilot associations, port authorities, and ship operators. The effectiveness of the present aids to navigation is relatively high based on the infrequent occurrence of grounding in U.S. waterways. It may be hypothesized, therefore, that the present system of aids represents near optimum configurations and that an analysis of both the present aid configurations and the physical dimensions of the waterways will provide a great deal of insight in establishing design criteria for aids to navigation. This report presents the findings of such an analysis.

For this analysis, information about the physical characteristics and present aids to navigation of 32 major U.S. ports was collected and entered into a computer data file. This file was then analyzed to ascertain the relationships between the characteristics and to determine the frequency of these relationships. The data collection was limited to major port areas. Inland rivers, the intercoastal waterway, and most of the Great Lakes were excluded from this analysis. The ports selected for analysis are listed in Table 1-1 by region.

TABLE 1-1. PORTS ANALYZED

EAST COAST	WEST COAST	GULF COAST	GREAT LAKES
PORTLAND (ME)	LONG BEACH	TAMPA	DULUTH
BOSTON	LOS ANGELES	MOBILE	
PROVIDENCE	SAN FRANCISCO	NEW ORLEANS	
NEW LONDON	PORTLAND (ORE)	PORT ARTHUR	
NEW HAVEN	SEATTLE	HOUSTON/GALVESTON	
NEW YORK	JUNEAU	CORPUS CHRISTI	
ALBANY	VALDEZ		
PHILADELPHIA	HONOLULU		
BALTIMORE	COOS BAY		
CHESAPEAKE BAY			
NORFOLK			
WILMINGTON (N.C.)			
CHARLESTON (S.C.)			
SAVANNAH			
JACKSONVILLE			
MIAMI			

1.1 CONDUCT OF THE ANALYSIS

Using the most current USCG navigational charts, data descriptive of the physical dimensions (geographic) and aids to navigation in each port were documented for the four waterway categories shown in Figure 1-1. These categories are defined as follows:

> Straight Channel. A waterway between turns or larger areas of water, delineated by dashed lines on navigation charts.
>
> Turn. A change in direction of the waterway coming out of one straight channel and going into another. Channels approximately 1/4 nm in both directions are considered part of the turn.
>
> Bay. An open area of water with no dredged area or delineation of channels. Boundaries are land masses.
>
> River. A river on chart. Boundaries are the river banks.

The physical data compiled for the four waterway categories were channel width, depth, length, turn angle, and turn type (dredged configuration). The aids to navigation data compiled for the four waterway categories were configuration of buoys (day and night), aid spacing (day and night), presence of range lights or beacons, relative occurrence of flash rates, number of buoys per mile in the daytime, and number of lights per mile at night. The remaining data were code numbers and chart numbers which allowed retrieval of data from the computer data base and cross-reference to charts. Table 1-2 summarizes the applicability of the data to the four waterway categories.

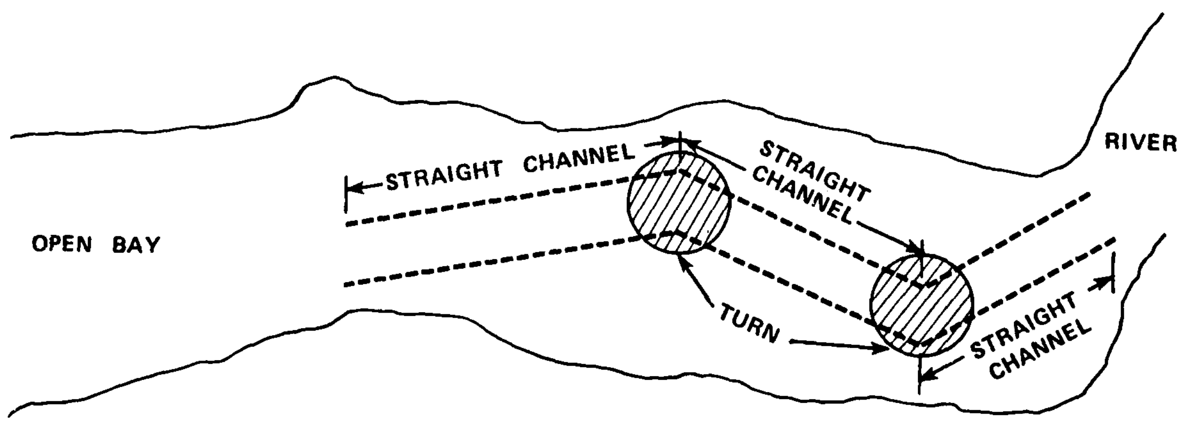

Figure 1-1. Four Waterway Categories

TABLE 1-2. APPLICABILITY OF DATA TO WATERWAY CATEGORIES

	HARBOR SEG. NO.	CHANNEL TYPE	DEPTH	WIDTH-IN	WIDTH-OUT	ANGLE	TURN TYPE	LENGTH	CHART NO.	COMMENT	CHANNEL CONF. DAY	AID SPACING DAY	CHANNEL CONF. NIGHT	AID SPACING NIGHT	RANGE	BEACONS	FLASH RATE	NO. BUOYS/MILE/DAY	NO. LIGHTS/MILE/NIGHT
BAY	●	●	⊙	⊙	⊙			●	●	●					●	●	●	●	●
RIVER	●	●	⊙	⊙	⊙			●	●	●					●	●	●	●	●
STRAIGHT CHANNEL	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●
TURNS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

● INFORMATION GATHERED

⊙ AVERAGED NUMBER WHERE APPLICABLE

Information on the rivers and bays was limited. When possible, averaged widths of the rivers and bays were entered; where there were different depths, the shallowest was chosen. Dividers were used to measure the length and width of those channels not entered in the chart tabulation table. (Dashed lines delineating the channels on the charts were used as a basis for measurement.) Depth would either be taken off the tabulation table or directly off the channel. Only channels with depths of 29 feet or greater were considered for this analysis. For turns, the type of turn was entered, and the angle of the turn was measured using parallel scales and the chart's compass rose. The actual delineation of the turn on the chart determined its type: noncutoff, cutoff, or bend. (See Figure 1-2.) Figure 1-3 shows the distance over which markings for a turn were considered as part of the turn aid configuration.

Of the 835 entries, 47 percent were straight channels; 46 percent were turns; seven percent were rivers and bays. (The mileage of the straight channels, rivers, and bays studied is given in Table 1-3.) This analysis addressed only the two larger (by occurrence) waterway categories: straight channels and turns. The initial analysis addressed the physical characteristics of length, width, and depth and the interrelationships of the three. These findings are presented in Sections 2 and 3. The final analysis addressed the present aids to navigation and their relationships with physical channel dimensions. These findings are presented in Sections 4 and 5.

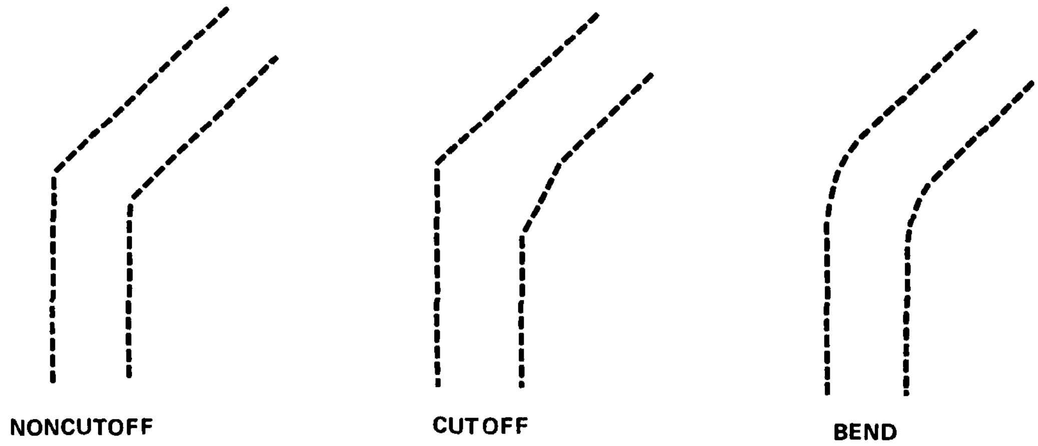

Figure 1-2. Types of Turns

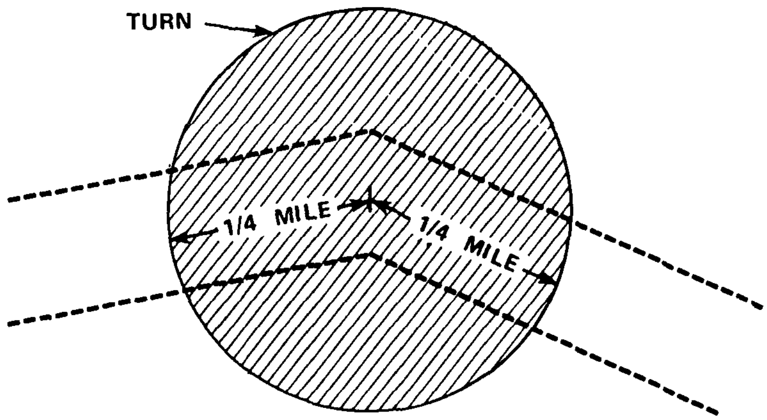

Figure 1-3. Distance Considered for Turn Aid Configuration

TABLE 1-3. MILEAGE STUDIED

	U.S. Waterways with Depth of 29 Feet or Greater	
	Nautical Miles	Percentage
Bays	347.4	26
Rivers	224.05	17
Straight Channels	747.6	57
	1319.05	100

1.2 SUMMARY OF FINDINGS: PHYSICAL CHARACTERISTICS AND AID CONFIGURATIONS FOR STRAIGHT CHANNELS AND TURNS

The following findings were derived from an analysis of waterways with a depth of 29 feet or greater in all major U.S. coastal harbors.

- There are approximately 750 nm of straight channels.
- There are approximately 575 nm of bays and rivers.
- There are 385 turns between straight channel segments.
- The majority of straight channels tend to be narrow.
    - 39 percent are 300 to 500 feet wide
    - 37 percent are 500 to 700 feet wide
    - 24 percent are 700 feet plus wide
- The narrow straight channels tend to be shorter than the wider channels. Mean lengths were:
    - 1.48 nm for channels 300 to 500 feet wide
    - 1.56 nm for channels 500 to 700 feet wide
    - 2.89 nm for channels 700 feet plus wide
- The narrow channels tend to be more shallow than the wider channels. Mean depths were:
    - 36.2 feet for channels 300 to 500 feet wide
    - 39.0 feet for channels 500 to 800 feet wide
    - 39.2 feet for channels 800 feet plus wide

- Turn configurations tend to occur with equal frequency.

  - 38 percent of turns are noncutoff
  - 34 percent of turns are cutoff
  - 28 percent of turns are bends

- The turn configurations with a larger available turn radius tend to be selected for larger angle turns. The mean turn angle of each turn configuration follows:

  - 16.9 degrees for noncutoff
  - 31.0 degrees for cutoff
  - 49.0 degrees for bend

- Sixty-one percent of all straight channels are marked in part with buoys; the other aids available are beacons and range lights. Only six percent of the straight channels are marked with buoys alone.

- The gated buoy configuration is the most prevalent standard configuration for straight channels.

  - 23 percent of straight channels are gated
  - 18 percent of straight channels are one side
  - 10 percent of straight channels are staggered

- The mean distance between positions in the channel where buoys are abeam of own ship is nearly equivalent for all three standard configurations.

  - gated: .872 nm (day), .975 nm (night)
  - staggered: .690 nm (day), .579 nm (night)
  - one side: .751 nm (day), .941 nm (night)

- Spacing of aids appears to be relatively independent of channel width.

- Gated configurations tend to be used in longer, wider straight channels while staggered and one side configurations tend to be used in shorter more narrow straight channels. Mean values are:

  - gated: 3.1 nm long, 667 feet wide
  - staggered: 2.1 nm long, 468 feet wide
  - one side: 1.7 nm long, 704 feet wide

- Staggered and one side configurations may be selected for narrow channels to provide increased maneuvering room when buoys are abeam.

- The one side configuration is likely to be a single buoy between turns, not necessarily a long row of single buoys.

- The density of aids in straight channels is approximately one and one-half times greater for the gated configuration versus the staggered or one side configuration.

    - gated: 2.29 aids/nm (day), 2.05 aids/nm (night)
    - staggered: 1.45 aids/nm (day), 1.73 aids/nm (night)
    - one side: 1.33 aids/nm (day), 1.06 aids/nm (night)

- The occurrence of one buoy and two buoy markings of turns is approximately equal and is nearly independent of turn configuration (noncutoff, cutoff, or bend) and turn angle.

    - 25 percent of turns: single buoy markings
    - 21 percent of turns: two buoy markings
    - 6 percent of turns: three buoy markings
    - 3 percent of turns: four plus buoy markings
    - 27 percent of turns: none
    - 18 percent of turns: other

- Difficulties in navigating larger turns may be mitigated by increases in the available turn radius thus reducing the requirement to provide more buoys for large angle turns.

- The prevalent flash period for lighted buoys in straight channels is four seconds.

- The prevalent flash periods for lighted buoys in turns are four seconds and quick-flash.

Section 2

PHYSICAL DIMENSIONS OF STRAIGHT CHANNELS

2.0 INTRODUCTION

This section deals with the actual physical dimensions of straight channels. The three major considerations of this analysis are length, width, and depth. Separate subsections that follow are devoted to each variable as well as the interactions between the three variables.

2.1 SUMMARY OF FINDINGS FOR STRAIGHT CHANNELS

For the 395 straight channels studied (totaling 747.6 nautical miles), the mean and standard deviations of the three main physical variables were:

	Mean	Std Deviation
• Length	1.898 nm	2.02 nm
• Width	595.94 ft	289.95 ft
• Depth	37.13 ft	4.51 ft

The standard deviation of length does not imply that there are negative values. Refer to Figure 2-1 for clarification of the distribution.

In summary, the physical data for straight channels indicate there is a large percentage of short, narrow, and shallow channels compared to the small percentage of long, wide, and deep channels. The longer, wider, and deeper channels tend to be natural channels and are located toward the seaward side of the ports. Channels become progressively restrictive going inland for obvious physical reasons.

2.2 ANALYSIS OF THE LENGTH OF STRAIGHT CHANNELS

The bar graph in Figure 2-1 shows the distribution of channel lengths as a percentage of all straight channels. Note that the greatest percentage is made up of shorter channels. Seventy-two percent are two nautical miles or less in length, and more than 45 percent are one nautical mile or less in length. This high percentage of short channels implies a great deal with regards to aid spacing since aid spacing can typically be no longer than half the length of the channel. The channel length data imply that consideration must be given to maneuvering in and out of turns when evaluating performance in straight channels.

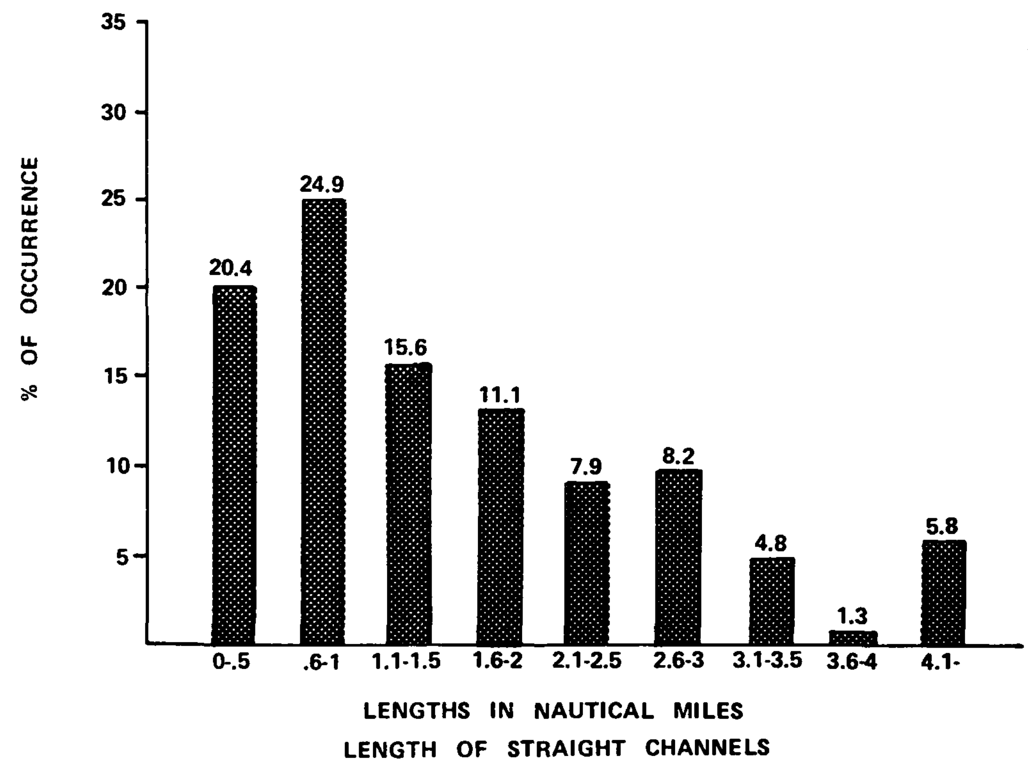

Figure 2-1. Distribution of Channel Length as a Percentage of Straight Channels

2.3 ANALYSIS OF THE WIDTH OF STRAIGHT CHANNELS

Although the width-in and the width-out of each channel were recorded, the mean width was used to reflect an overall average. Figure 2-2 gives the distribution of mean widths. Seventy-six percent of the straight channels are under 700 feet wide with 39 percent between 300 and 499 feet and 37 percent between 500 and 699 feet. The two most prevalent channel widths are 400 to 449 feet and 600 to 699 feet with 25 percent and 24 percent, respectively.

2.4 ANALYSIS OF THE DEPTH OF STRAIGHT CHANNELS

Only channels with depths of 29 feet or greater were considered in this analysis. Figure 2-3 shows the distribution of different channel depths as a percentage of all straight channels. Ninety percent of all straight channels are 40 feet or less in depth; 46 percent are 36 feet or less in depth. Information determining dredged versus natural depths was not collected, nor was the existence of banks. These data imply that large vessels with drafts greater than 40 feet will be limited to only a handful of harbors of which inland penetration will be limited. Table 2-1 lists common ship types and their particulars of design. Note the drafts.

2.5 INTERACTIONS OF LENGTH, WIDTH, AND DEPTH

Figure 2-4 indicates that narrow channels tend to be shorter and get progressively wider as they get longer. But as shown in Figure 2-5, only 21 percent of the total mileage of straight channels is over 700 feet wide.

In an analysis of length and depth (see Figure 2-6), it was found that the longer channels are dredged deeper or, more likely, are naturally deeper. The operational implication is that larger ships that require deeper channels have longer straight channels available.

The bar graph in Figure 2-7 shows a relationship between width and depth. Channels that are deeper tend to be wider. These data may imply that large vessels that require deeper channels also require wider channels.

TABLE 2-1. COMMON SHIP TYPES AND THEIR DESIGN DATA

Type	Name	Displacement (dwt)	Length (ft)	Beam (ft)	Draft (ft)
Ferry	Staten Island	2,721	310	70	12
Bulk/Reefer/ Container	America	2,000	295	45	14
Tugboat	Jalbar	1,010	126	36	17
Bulk	Altnes	4,550	301	49	21
Tanker	Marindus	10,000	470	60	23
Submarine Tender	Frank Cable	23,000	643	85	25
Ice Breaker	Polar Star	13,190	399	83	28
Tanker	Exxon Galveston	27,240	552	95	29
Dry Cargo	Amfitriti	16,952	468	69	31
Navy Tanker	Cimmarron	26,110	591	88	31
Containership	Euroliner	40,800	798	100	32
RO/RO	Boogabella	31,500	749	105	35
Barge Carrier	Yelius Tuchik	36,382	874	115	36
LNG	Methania	$131,500m^3$	918	134	36
LNG	El Paso Southern	$126,000m^3$	846	135	37
LNG	HILLI	$125,000m^3$	961	137	37
LNG	Gemini	$125,000m^3$	936	143	37
Tanker	Esso Portland	50,084	645	120	37
Crane Ship	Sarita	42,000	677	121	37
Tanker	Brooks Range	165,000	906	173	55
Tanker	Sar Diego	188,500	952	166	59
Tanker	Esso Pacific	508,000	1280	233	83

*Ships accommodated in 40 foot depth channels.

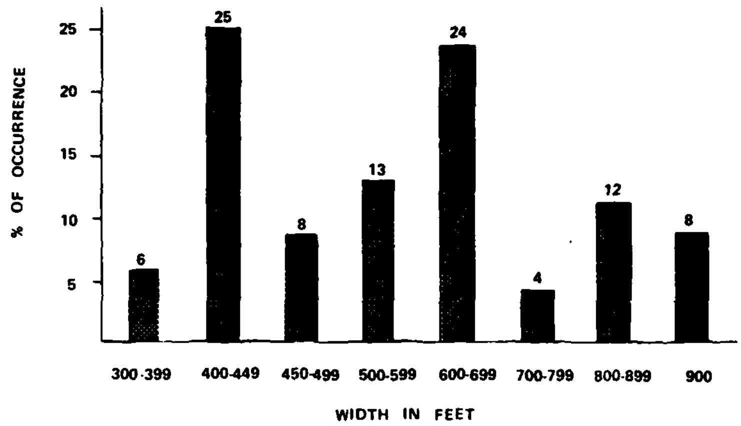

Figure 2-2. Distribution of Mean Channel Widths as a Percentage of All Straight Channels

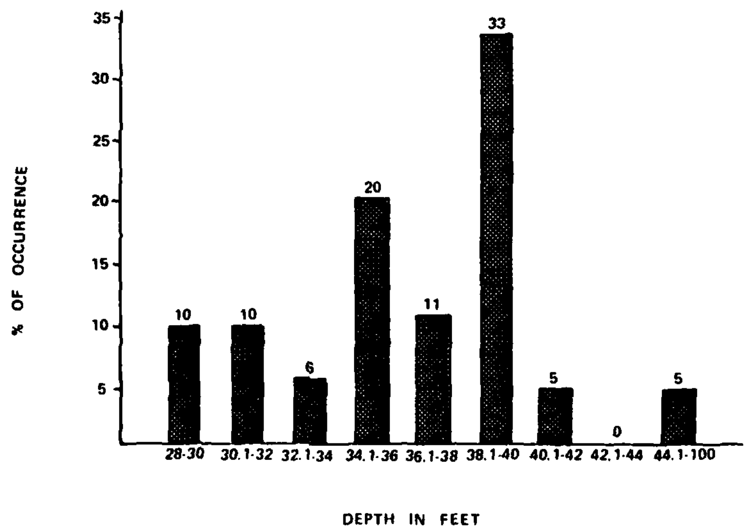

Figure 2-3. Distribution of Channel Depths as a Percentage of All Straight Channels

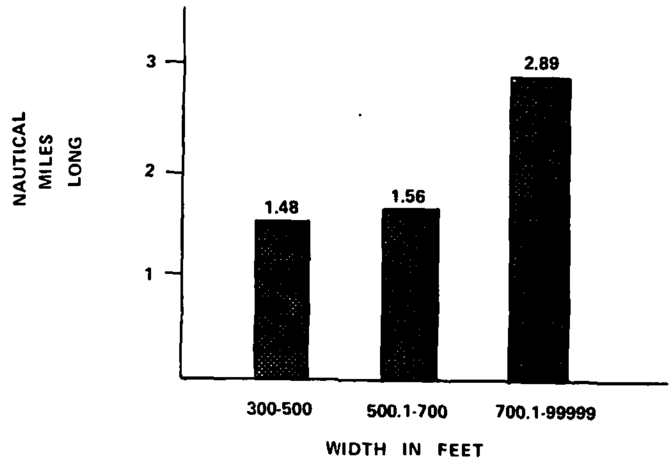

Figure 2-4. Average Length of Straight Channels Versus Width

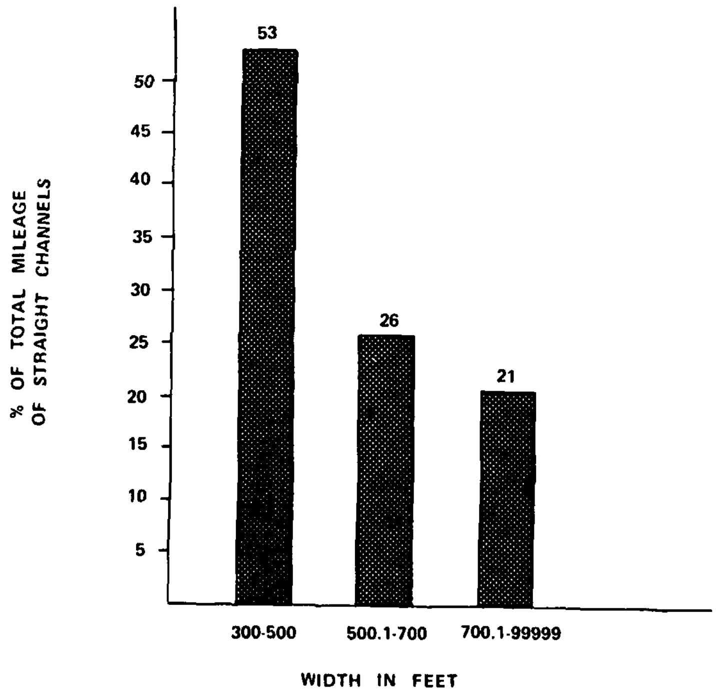

Figure 2-5. Distribution of Channel Widths as a Percentage of Total Mileage of Straight Channels

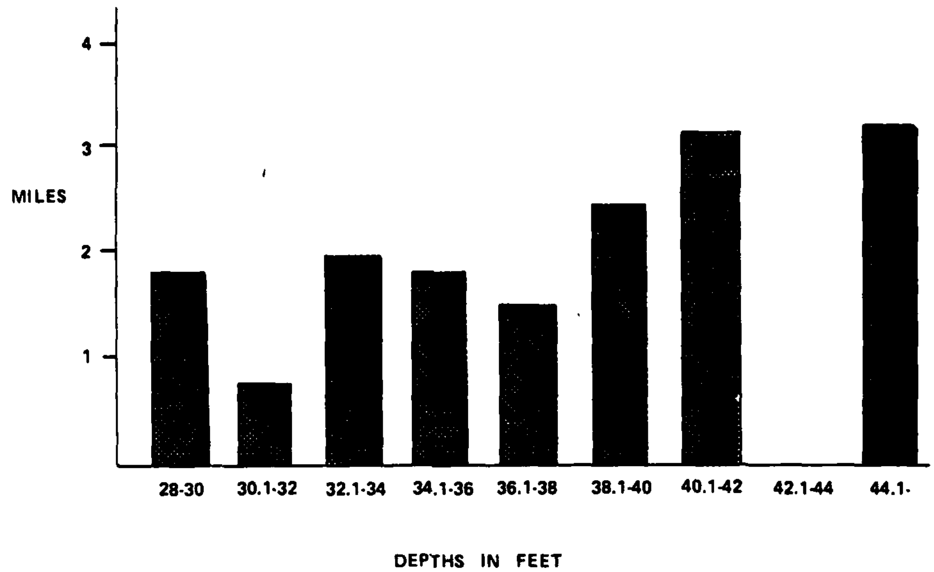

Figure 2-6. Average Length of Straight Channels Versus Depth

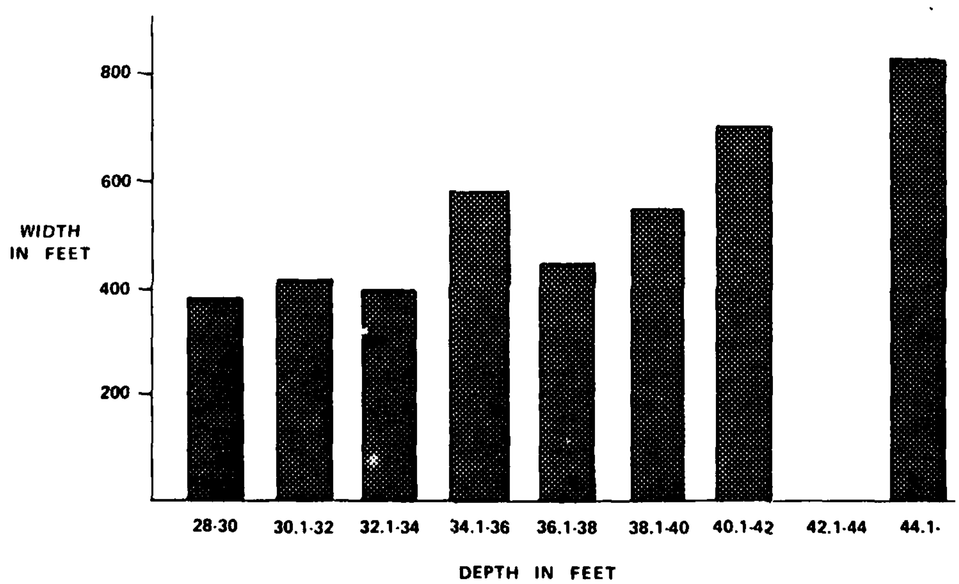

Figure 2-7. Average Width of Straight Channels Versus Depth

Section 3

PHYSICAL DIMENSIONS OF TURNS

3.0 INTRODUCTION

The physical data collected for turns was the same as for straight channels with a few exceptions. There were no lengths involved except with some of the longer sweeping bends. These amounted to approximately 50 nautical miles with most being in the Houston/Corpus Christi harbors. Depths and widths, as could be determined, parallel the findings for straight channels. Physical data common only to turns are the turn configurations (see Figure 1-2) and the angle of turns. This section addresses the distribution of turn configuration, the occurrences of different angles, the distribution of turns by width, and the interaction of all three.

The determining factor of turn type as cutoff, noncutoff, or bend was delineation on the navigational charts. A series of cutoff turns with extremely short straight channels (less than 1/4 nm) connecting them was counted as one bend, regardless of delineation.

3.1 SUMMARY OF FINDINGS FOR TURNS

For the 380 turns analyzed, the breakdown according to turn type was:

- 144 turns were noncutoff
- 129 turns were cutoff
- 107 turns were bends

The mean angle of turn for each turn type was:

- 16.9 degrees for noncutoff
- 31.0 degrees for cutoff
- 49.0 degrees for bend

3.2 ANALYSIS OF TURN CONFIGURATION

As can be seen in Figure 3-1, the distribution of turns by configuration is quite even. The noncutoff turns are normally the result of the placement of turn markings combined with their channel boundary delineation. The cutoff turns are defined by both dredging and aids to navigation placement. Cutoff turns provide a larger available turn radius. Bends tend to occur in the meandering river areas with long sweeping turns of large radius.

3.3 ANALYSIS OF TURN ANGLE

Figure 3-2 shows that of all the turns analyzed 77 percent are 40 degrees or less, 34 percent are between 21 and 40 degrees, and 43 percent are 20 degrees or less. Of the 23 percent that are 41 degrees or greater, many represent turns onto a secondary channel as shown in Figure 3-3.

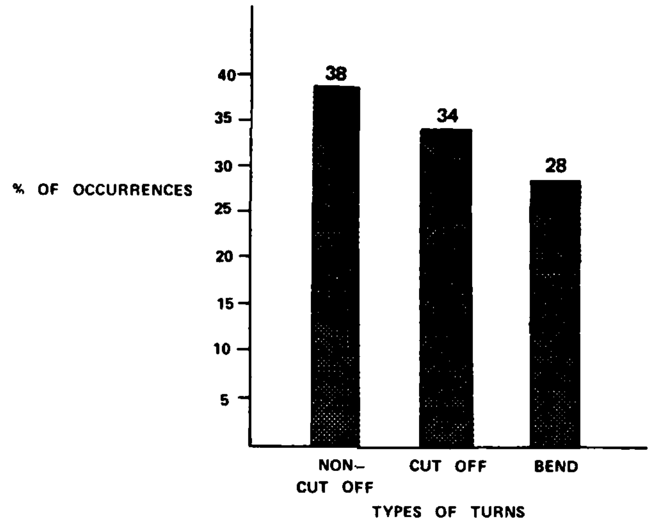

Figure 3-1. Frequency of Occurrence of Turn Configuration

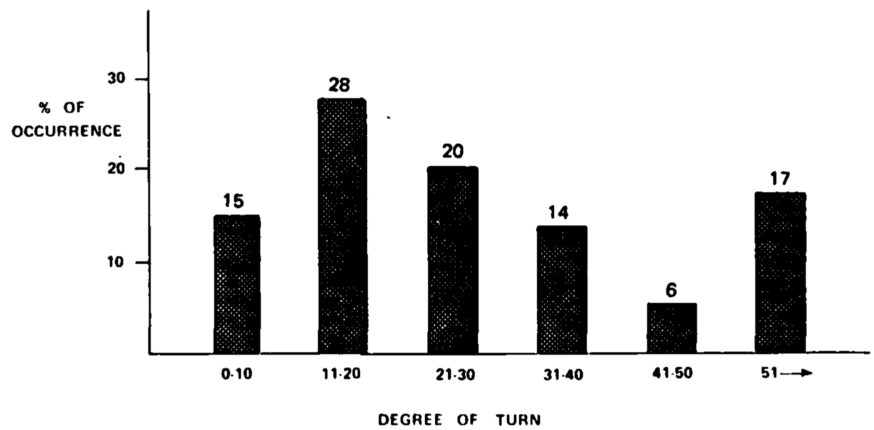

Figure 3-2. Frequency of Occurrence of Turn Angles

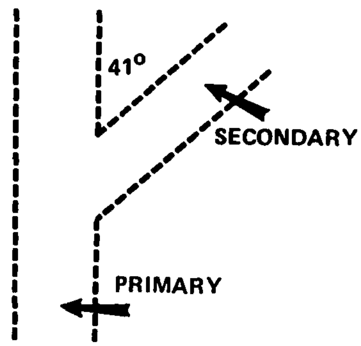

Figure 3-3. Delineation of Turn Into Secondary Channel

3.4 ANALYSIS OF TURN WIDTHS

The distribution of turns by width parallels the findings of straight channels. There is a high frequency of narrow turns. Figure 3-4 shows that 82 percent of the turns are between 300 and 700 feet in width. Of these, 53 percent are between 300 and 500 feet in width. These data imply that most turns in the waterways will accommodate only one-way traffic of large vessels.

3.5 INTERACTIONS OF TURN CONFIGURATIONS, TURN ANGLES, AND TURN WIDTHS

In comparing turn configuration and degree of angle, a definite relationship can be seen in Figure 3-5. The noncutoff turns decrease in number as the angle increases. The cutoff turns follow a bell shaped curve, clustering mainly around the 20 to 40 degree turns. The bends display a high percentage of occurrence for large angles and a lower percentage of occurrences for small angles. Since cutoff turns provide larger turning radii, it might be hypothesized that larger radii are required for piloting through large angle turns. The fact that the bends should occur so often with large angles is a good indication that large radii are also preferable for negotiating very large angle turns. Bends that occur at smaller angles most likely occur because of the nature of the land mass.

Data in Figure 3-6 show that the occurrence of turn configurations by width generally follow the overall occurrence of turns by width. (See Figure 3-4.) These trends imply that there is little dependence of turn configuration on channel width.

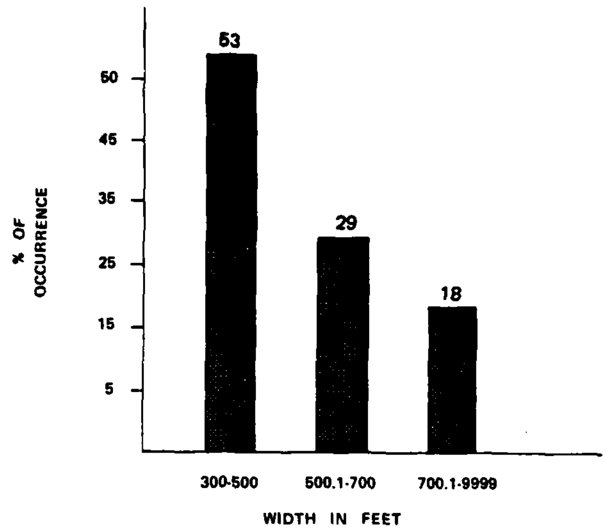

Figure 3-4. Frequency of Occurrence of Turns by Width

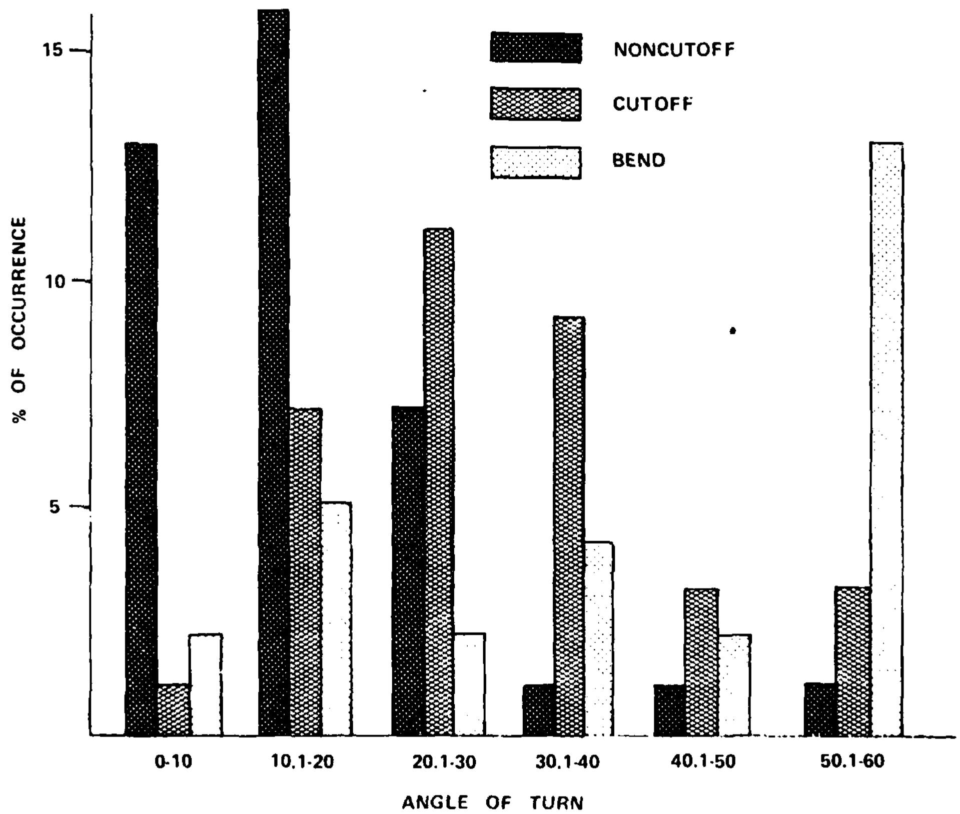

Figure 3-5. Relative Occurrence of Turn Configuration by Turn Angle

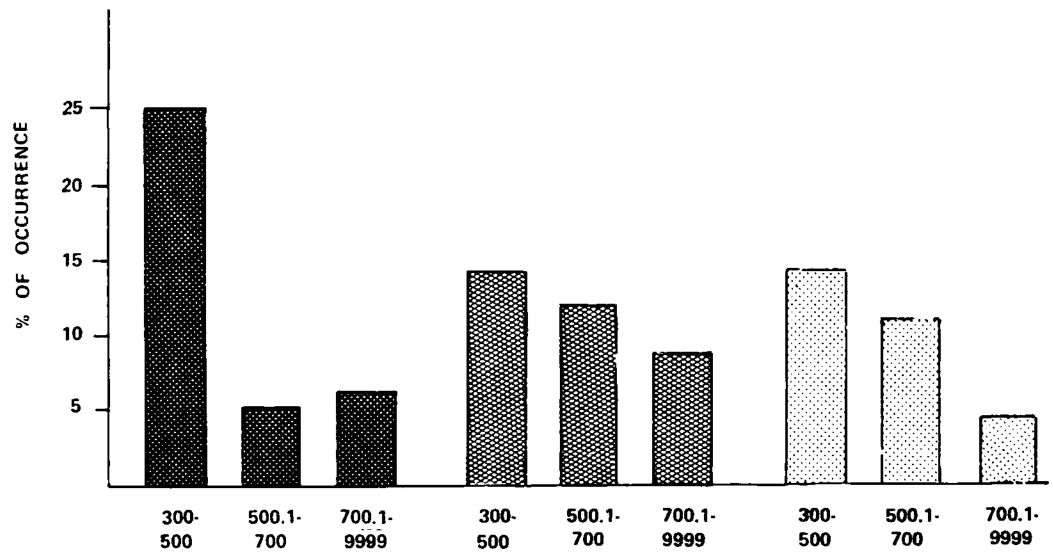

Figure 3-6. Frequency of Occurrence of Turn Configuration by Width

Section 4

AIDS TO NAVIGATION IN STRAIGHT CHANNELS

4.0 INTRODUCTION

The aid to navigation data compiled for straight channels included: aid configuration for day and night, aid spacing in straight channels for day and night, whether or not beacons and range lights exist, relative occurrence of flash rates, number of buoys per mile for day, and number of lights per mile for night. The five most standard configurations were identified as none, gated, staggered, one side, and combination (gated plus staggered). (See Figure 4-1.) The spacing entered for each combination is shown to be the distance between aids on a single side of the channel. No spacing is shown for the combination configuration in Figure 4-1. If there were markings on the channel that were not representative of the standard configurations, the code for 'other' was entered for aid configuration, and zero was entered for aid spacing. Figure 4-2 shows typical 'other' configurations where aids are irregularly spaced. Where there was a similarlity to one of the standard configurations but spacing was somewhat irregular, the standard configuration and the average spacing were entered. Generally, only the configuration of buoys was evaluated and coded. In some cases, beacons were placed at regular intervals at the channel edge. In such cases, their configuration and spacing were entered. Figure 4-3 shows a gated configuration of beacons that occasionally occurred. If the beacons were not on or extremely close to the delineation of the channel edge on the navigational chart, it was not considered as part of the channel configuration but was entered as 'yes' for existence of beacons. Beacons up to approximately 1/2 nm from the channel were entered as existing. Range lights were entered in the data base as 'yes' or 'no' for existing.

The determination of the aid configuration in many cases was relatively subjective. This was even more evident when entering a value for aid spacing. In the real world, aids are placed where they are needed or can be reliably anchored. These positions do not usually coincide exactly with standard configurations. The findings in this report should thus be analyzed with that in mind.

All configuration data and spacing data were evaluated for day and night. Under day conditions, all aids were considered, including daymarks, and nun and can buoys. Under night conditions, only the lighted aids were considered. For night conditions, the relative occurrence of flash rates and flash codes was noted. For both day and night conditions, the density of aids (number of aids per mile) was calculated and recorded for each straight channel.

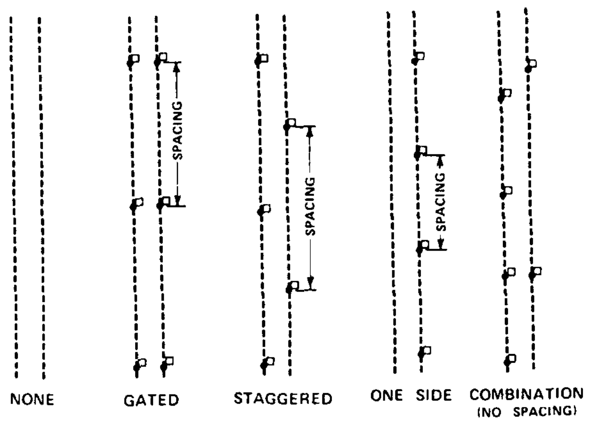

Figure 4-1. Typical Aid Configurations for Straight Channels

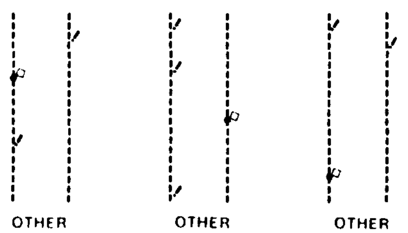

Figure 4-2. Typical 'Other' Configurations, No Spacing Recorded

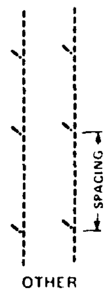

Figure 4-3. Example of Gated Beacon Configurations

4.1 SUMMARY OF RESULTS

An overall summary of the occurrence of aids in waterways (defined as bays, rivers, straight channels, and turns) is shown in Table 4-1. Buoys appear in 61 percent of the waterways, but they are utilized alone in only six percent of the waterways. The most frequent configurations with buoys are buoys plus beacons (24 percent) and buoys plus beacons plus range lights (29 percent). The next most frequent occurrence of aids is beacons alone (16 percent) and beacons plus range lights (16 percent). These data indicate the majority of piloting in waterways involves the utilization of a combination of aids: buoys, beacons, or range lights. Only six percent of the waterways have no aids at all.

Table 4-2 indicates the frequency of occurrence of the standard and other buoy configurations. Percentage data are compiled by number of channel segments and by total mileage. Thirty-eight percent of the total number of channels have no buoys. As indicated in Table 4-1, however, the majority of these must be marked with beacons and/or range lights since only six percent of the total number of waterways have no USCG aids at all. Of the standard configurations, gated is the most frequent configuration (23 percent), followed by one side marking (18 percent). These percentages vary somewhat if the total mileage of the channel segments is considered. The gated configuration represents 38 percent of the total straight channel mileage in the waterways while the one side configuration represents 17 percent. Staggered buoys represent 12 percent of the total mileage. Gated, staggered, or one side markings are used in 67 percent of the total straight channel mileage. Combinations and other configurations account for only 15 percent by mileage.

The aid spacing by configuration is summarized in Table 4-3 for both day and night conditions. The mean, standard deviation, and minimum and maximum values are tabulated. If the distance between occurrences of aids abeam is considered (equal to spacing for gated and one side and one-half the spacing for staggered), the mean value of distance between aids abeam during the day is approximately 3/4 nm (.872 nm, .751 nm, and .69 nm, respectively). The standard deviation of the distance between aids abeam is approximately 1/2 nm (.447 nm, .550 nm, and .421 nm, respectively). These values are seen to increase slightly at night due to the absence of the nun and can buoys and day marks in the calculations. The spacing for staggered buoys appears to be slightly less at night.

The minimum and maximum spacing values provide an interesting insight in that the maximum spacing appears to roughly coincide with daytime detection distances for large lighted buoys (2 to 3 nm). The maximums for staggered buoys can be divided by two to determine the distance to the next buoy.

TABLE 4-1. OCCURRENCE OF AIDS IN ALL WATERWAY CATEGORIES

BUOYS	BEACONS	RANGE LIGHTS	% OF OCCURRENCE IN SEGMENTS
●	○	○	6%
●	○	●	2%
●	●	○	24%
●	●	●	29%
○	●	○	16%
○	●	●	16%
○	○	●	1%
○	○	○	6%

● EXISTING
○ NONE

TABLE 4-2. OCCURRENCE OF BUOY CONFIGURATIONS
IN STRAIGHT CHANNELS (DAY)

	No. of Channels	Percentage of No. of Channels	Total Mileage (nm)	Percentage of Total Mileage
None	149	38	136	18
Gated	91	23	290	38
Staggered	40	10	86	12
One Side	73	18	131	17
Combination	18	5	56	8
Other	24	6	52	7

TABLE 4-3. AID SPACING IN STRAIGHT CHANNELS (IN NM)

	DAY				NIGHT			
	MEAN	STD DEV.	MIN. VALUE	MAX. VALUE	MEAN	STD DEV.	MIN. VALUE	MAX. VALUE
01 GATED	.872 NM	.447 NM	.2 NM	2.4 NM	.975 NM	.486 NM	.2 NM	2.4 NM
02 STAGGERED	1.38 NM	.842 NM	.6 NM	4.0 NM	1.158 NM	.597 NM	1.2 NM	3.0 NM
03 ONESIDE	.751 NM	.550 NM	.3 NM	2.5 NM	.941 NM	.621 NM	.1 NM	2.5 NM
04 COMBINATION								

4.2 ANALYSIS OF CHANNEL LENGTH AND WIDTH VERSUS AID CONFIGURATION

The data in Table 4-2 indicates a dependence of aid configuration and channel length since the percentage of occurrence for configurations varied when calculated against the total number of channels and total mileage. Table 4-4 indicates the mean, standard deviation, and minimum and maximum length of channels for each standard aid configuration. The short mean length of channels with no buoys (.9 nm) and the small deviation about this value (.6 nm) imply that these channels may be sufficiently short so that the turn buoys at either end provide adequate marking for navigation. Note that the mean length of .9 nm is of an equivalent magnitude as the average distance between buoy abeam conditions (3/4 nm) for all configurations. These data indicate that turn markings at either end of short, straight channels should be evaluated with regard to providing adequate marking to navigate the straight channel between them without requiring additional buoys. The mean channel length for gated buoys (3.1 nm) is the greatest mean and may generally coincide with the prevalent occurrence of long, deep, wide channel dimensions discussed in Section 2.

Table 4-5 lists the mean channel width for each standard configuration. These data verify that the gated configuration is typically used for wider channels. The gated configuration may thus be utilized for large vessels in major ship channels. The relatively short mean lengths for staggered and one side (2.1 and 1.7 nm, respectively) would tend to coincide with shorter, more narrow, shallower channels. Data in Table 4-5 verify that typically staggered buoys are used in relatively narrow channels. Staggered configurations are thus probably utilized by smaller vessels. Interestingly, the staggered and one side combinations provide relatively more cross channel maneuvering room when buoys are abeam versus gated buoys. Such latitude may be desired by the pilots in narrow channels. Note also that the mean buoy spacing (.75 nm) for the one side configuration is approximately one-half the mean length for single side (1.7 nm) indicating that the one side configuration often occurs as a single buoy between turns, not as a row of single buoys over long distances.

4.3 ANALYSIS OF AID SPACING AND CHANNEL WIDTH

An analysis of width showed little dependence between these two variables. Table 4-6 lists the mean buoy spacing for the standard configurations for various channel widths. The dependence is less evident with the gated buoys. The small difference in mean values and the fact that spacing is slightly greater for narrow channels counter the hypothesis that greater buoy spacing may be desirable in wider channels; for the staggered configuration only the value for the narrow channels is significant since there were few entries for wider channels. The one side configuration values show the greatest dependence between channel width and buoy spacing. The mean values of spacing increase as the width increases.

TABLE 4-4. CHANNEL LENGTH CHARACTERISTICS VERSUS AID CONFIGURATION

	Mean Length	Std Deviation	Minimum Length	Maximum Length
None	.9 nm	.6 nm	.2 nm	3.5 nm
Gated	3.1	2.5	.3	10.9
Staggered	2.1	1.5	.5	6.1
One Side	1.7	1.5	.3	10.0
Combination	2.9	3.9	.3	18.0
Other	2.1	2.2	.3	9.0

TABLE 4-5. MEAN CHANNEL WIDTH VERSUS AID CONFIGURATION

	Mean Width	Std Deviation
Gated	667 ft	350 ft
Staggered	468	157
One Side	704	478

TABLE 4-6. SPACING FOR STANDARD AID CONFIGURATIONS BY CHANNEL WIDTH (DAY)

	Width (ft)	Mean Spacing (nm)	Std Deviation (nm)
Gated Spacing:	300 - 499	.928	.517
	500 - 699	.759	.312
	700 plus	.902	.438
Staggered Spacing:	300 - 499	1.276	.425
	500 - 699	1.2	.282
	700 plus	1.5	1.272
One Side Spacing:	300 - 499	.599	.326
	500 - 699	.844	.292
	700 plus	1.092	.774

4.4 ANALYSIS OF AID TO NAVIGATION DENSITY

An overall analysis of the number of aids per mile was made to find the buoy density across U.S. harbors. The data in Figure 4-4 summarize this analysis. Both day and night data are presented in order to amplify the general similarity. The outstanding data are that 40 to 45 percent of all waterways have no buoys. During the day, 34 percent of the waterways have from .1 to 1.5 aids per mile; at night, 38 percent of the waterways have from .1 to 1.5 aids per mile. During the day an additional 17 percent of the waterways have 1.6 to 3.0 aids per mile. The average number of aids per mile during the day for channels with aids is 2.5 aids per mile The average number of aids per mile during the night for channels with aids is 1.67 aids per mile.

Buoy density may also be calculated by configuration for just the standard configurations utilizing the mean spacing values listed in Table 4-3. Table 4-7 lists the mean aid density for both day and night conditions by configuration. The economy of utilizing staggered or one side configurations over gated is clearly indicated by a reduction in density without a decrease in the mean distance between buoys abeam.

4.5 ANALYSIS OF LIGHTING CHARACTERISTICS OF BUOYS IN HARBORS

An analysis of the flash rates and flash codes was made to determine the distribution of these variables across the channel markings. Figure 4-5 shows the distribution of lights by lighting characteristics. The two prevalent data points in this figure are that 30 percent of the aids are without lights and 47 percent of the aids display a 4-second flash rate. The standard 2.5-second flash buoys and 6-second flash buoys are infrequently used (11 percent and 2 percent, respectively). The low frequency of occurrence of quick-flash and Morse 'A' is explained by the fact that quick-flash aids are used almost exclusively for turns while the Morse 'A' buoys are generally used for sea lane demarcation and sea buoys on entrance channels.

TABLE 4-7. AID DENSITY BY CONFIGURATION

Configuration	Aid Density Day	Aid Density Night
Gated	2.29 aids/nm	2.05 aids/nm
Staggered	1.45	1.73
One Side	1.33	1.06

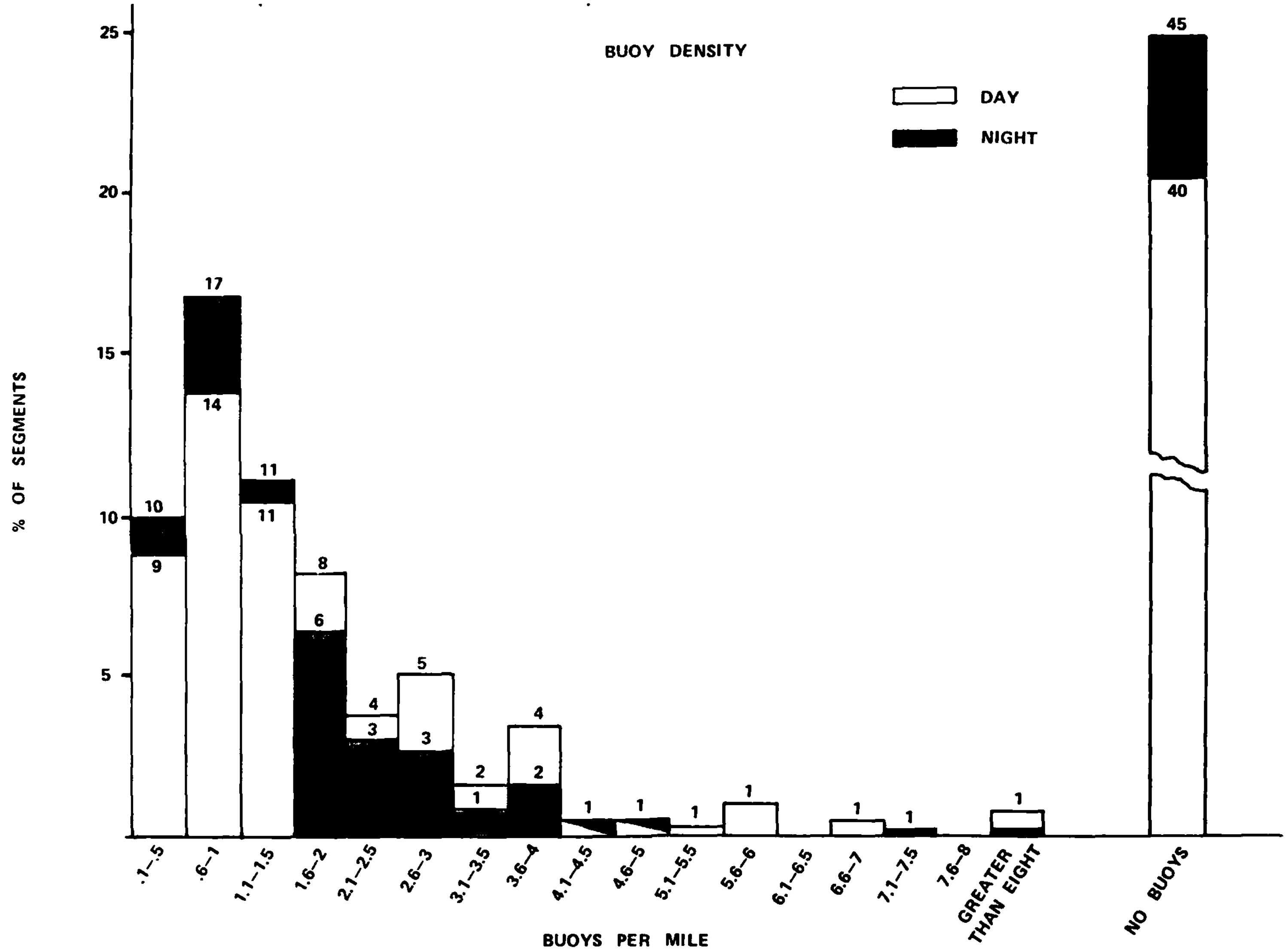

Figure 4-4. Buoy Density Across All Waterway Categories

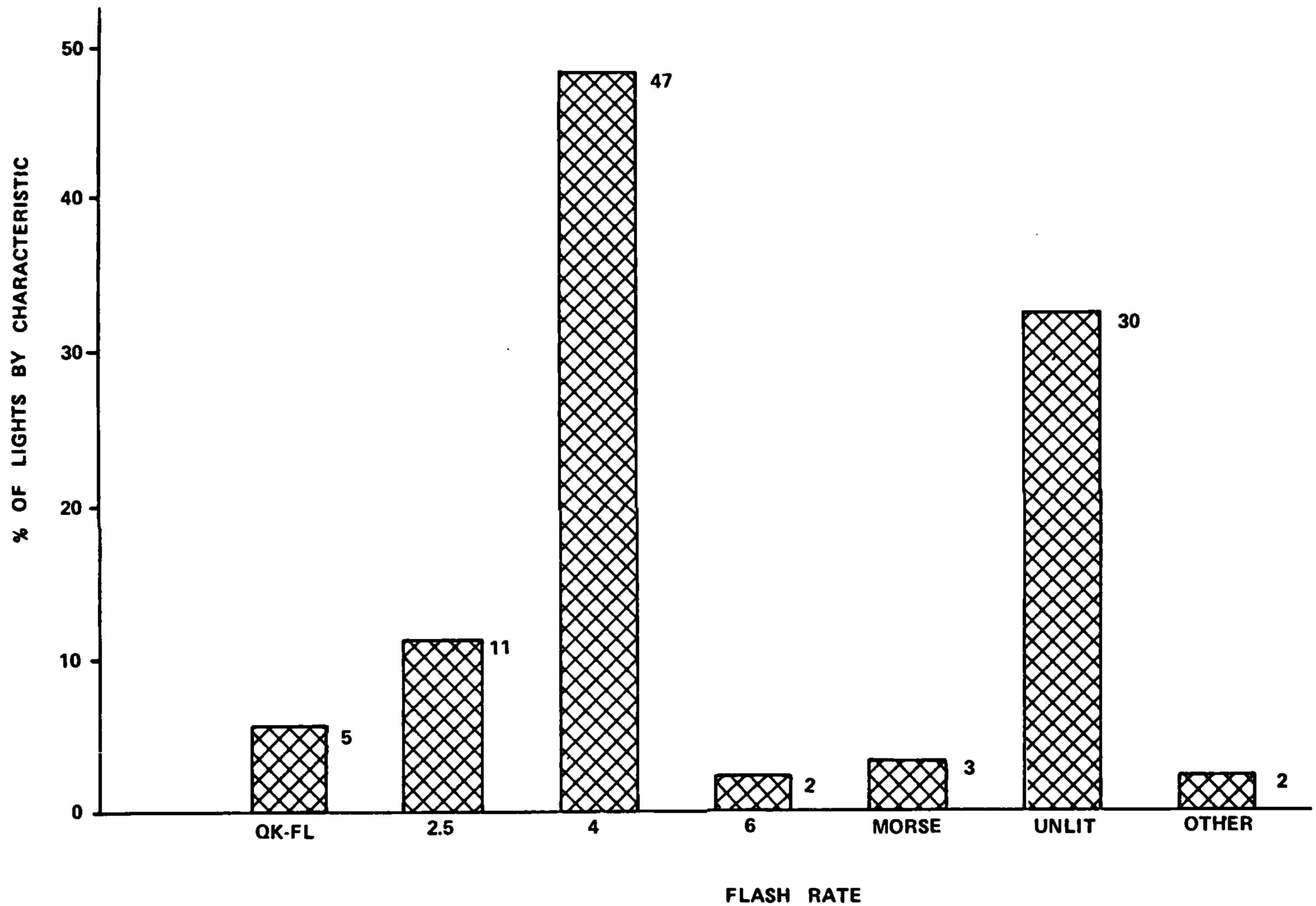

Figure 4-5. Frequency Distribution of Flash Codes and Flash Rates in All Waterway Categories

Section 5

AIDS TO NAVIGATION IN TURNS

5.0 INTRODUCTION

It was found that there were no absolute standards in regard to marking turns. The distribution of the physical characteristics of turns by aid configuration shows that turns occur in many forms. The fact that there were so many aid configurations adds to the complexity of the analysis. This section conveys some general observations and recognizes some noticeable traits of floating aids to navigation in turns.

5.1 SUMMARY OF AID CONFIGURATIONS FOR TURNS

The variety of turn markings by turn configuration is shown in Figure 5-1. The frequency of occurrence for each configuration is also noted. The single apex buoy and the gated buoys for the noncutoff turn represent the most prevalent markings, 17 percent and 15 percent, respectively. No predominant configuration is evident for the cutoff turn. The remaining configurations each represent one to five percent of the turn marking data base. Not shown in Figure 5-1 is the additional 18 percent of the turns with markings that have 'other' configurations, each of which is so special in design as to represent less than one percent of the turns in the data base. These percentages represent only turns with markings. Not included is that face that 27 percent of the turns in U.S. harbors have no buoys.

Analysis of the turn data with regard to the number of buoys per turn provides some indication of the trends in turn marking. Figure 5-2 shows the occurrence of the number of markings per turn configuration. These data have been normalized so that their collective sum is equal to 100 percent. One and two buoy configurations clearly dominate in noncutoff turns. One and two buoy markings are similarly frequent in cutoff turns, but there also appears to be a significant occurrence of three and four buoy configurations in cutoff turns. Bends appear to be equally marked with one, two, or four buoys.

The data in Figure 5-3 allow the formulation of some interesting hypotheses. As stated in Section 3, noncutoff configurations were generally used with small turn angles (0 to 20 degrees), and cutoff configurations were used with medium sized turn angles (20 to 40 degrees). We might expect, therefore, to find a relationship between turn angle and the number of buoys per turn. The data in Figure 5-3 show that for one and two buoy configurations the number of buoys per turn is not dependent on the turn angle. The reduced occurrence of 20 to 40 degree turns reflects the fact that there are relatively fewer of these turns versus 0 to 20 degree turns. As per Figure 5-2, three buoy and four buoy turn markings are relatively infrequent. We might thus conclude that while cutoff turns are typically provided for larger angle turns, the increased radius is alone sufficient to ensure safety, and the number of aids on the turn need not be increased.

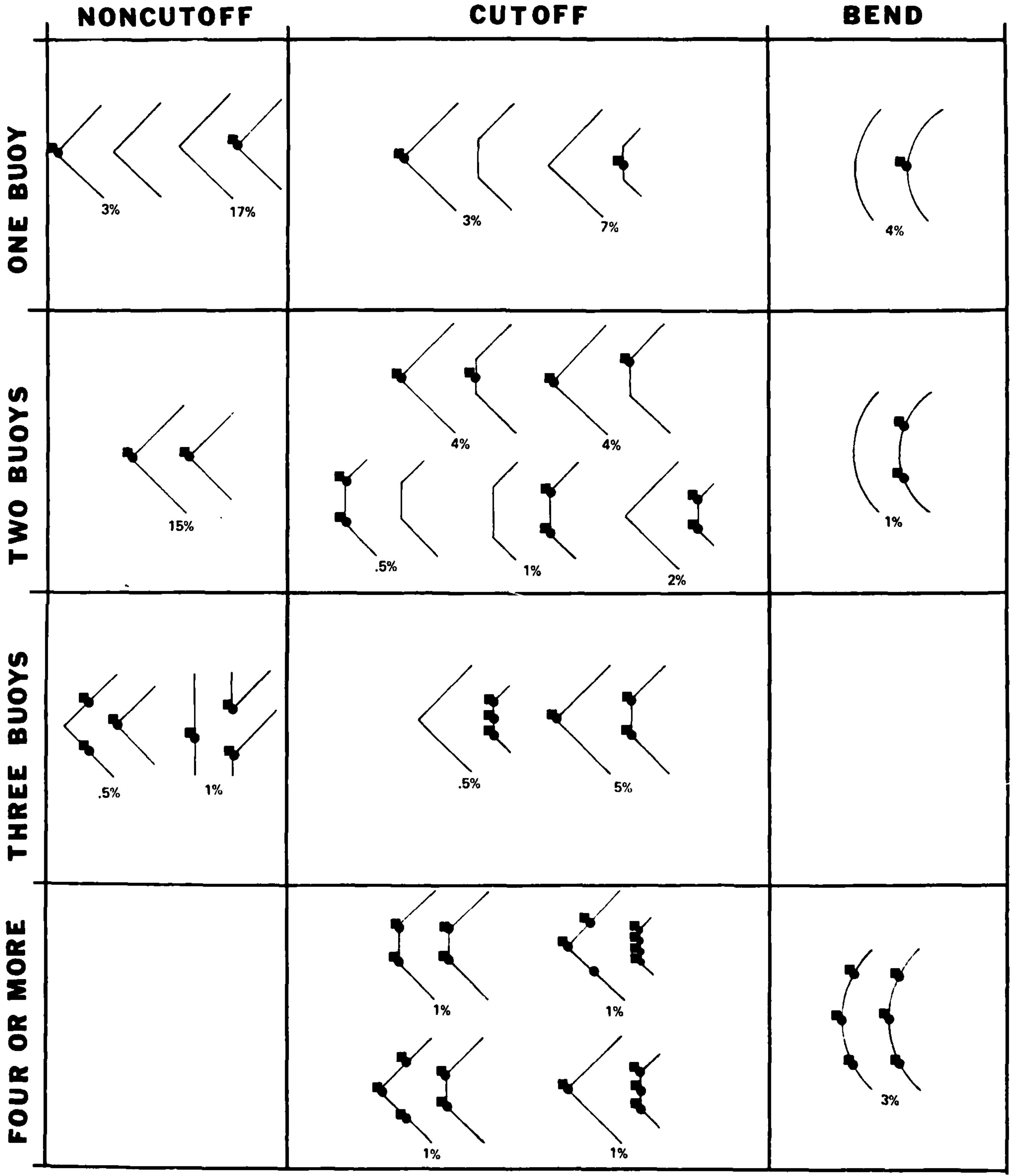

Figure 5-1. Frequency of Occurrence of Typical Aid Configurations for Turns

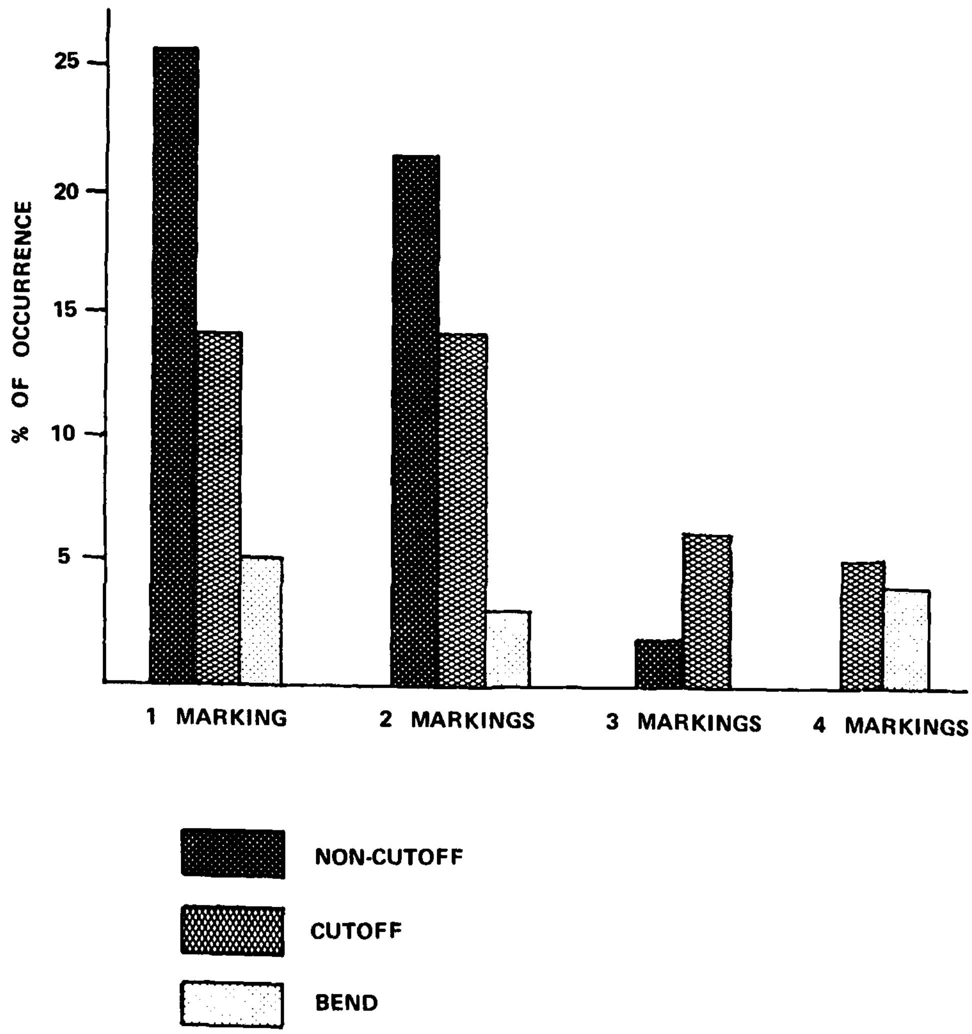

Figure 5-2. Frequency of Occurrence of Number of Turn Buoys by Turn Configuration

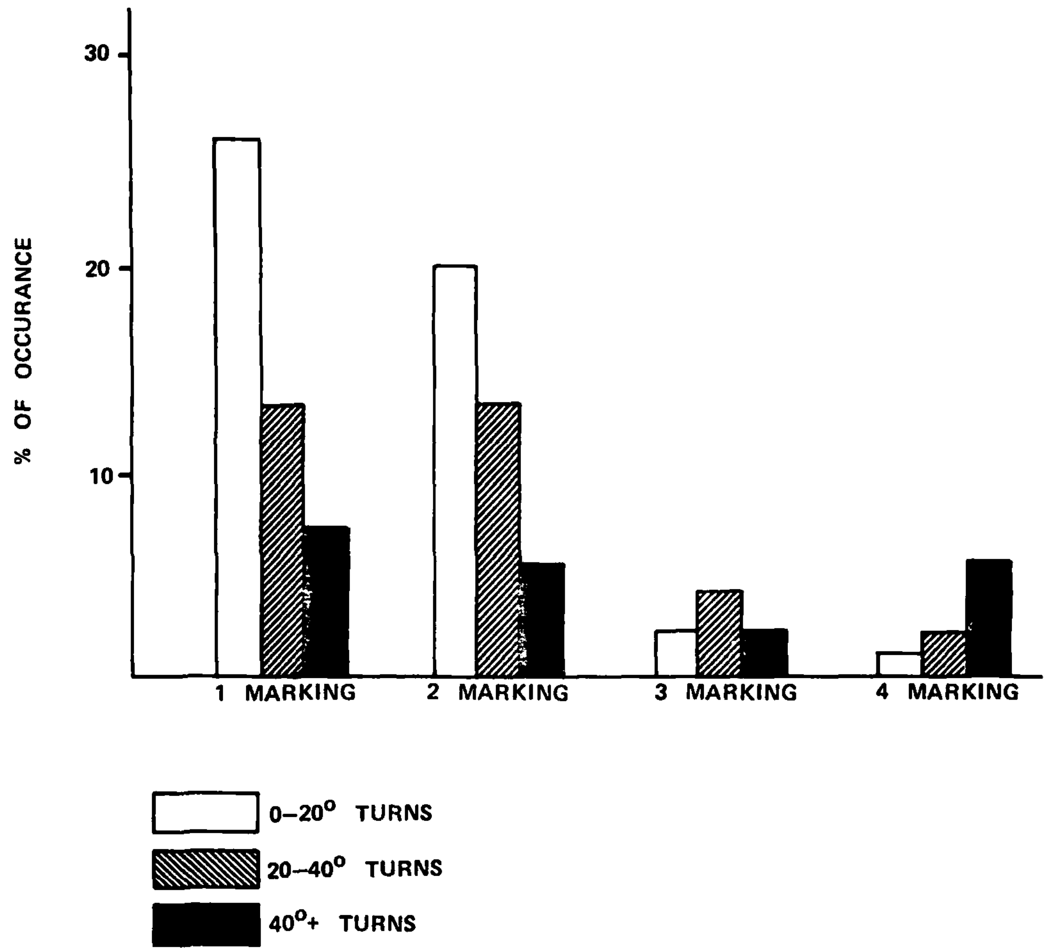

Figure 5-3. Turn Marking by Turn Angle

5.2 CHARACTERISTICS OF LIGHTS ON TURN BUOYS

The frequency of occurrence of flash characteristics of buoy lights in turns is shown in Figure 5-4. While 4-second flash periods dominated in straight legs, in turns the 4-second flash period occurs at about equal number to quick-flash. This is not surprising, however, considering the frequent use of quick-flash to mark the inside turn apex. Longer flash periods such as six seconds are virtually nonexistent in turns. This is probably due to the stated requirement by the pilots to use buoys visually to judge turn progress every few seconds. The 4-second flash buoys are probably provided as the pair buoy to the quick-flash buoy on the turn apex.

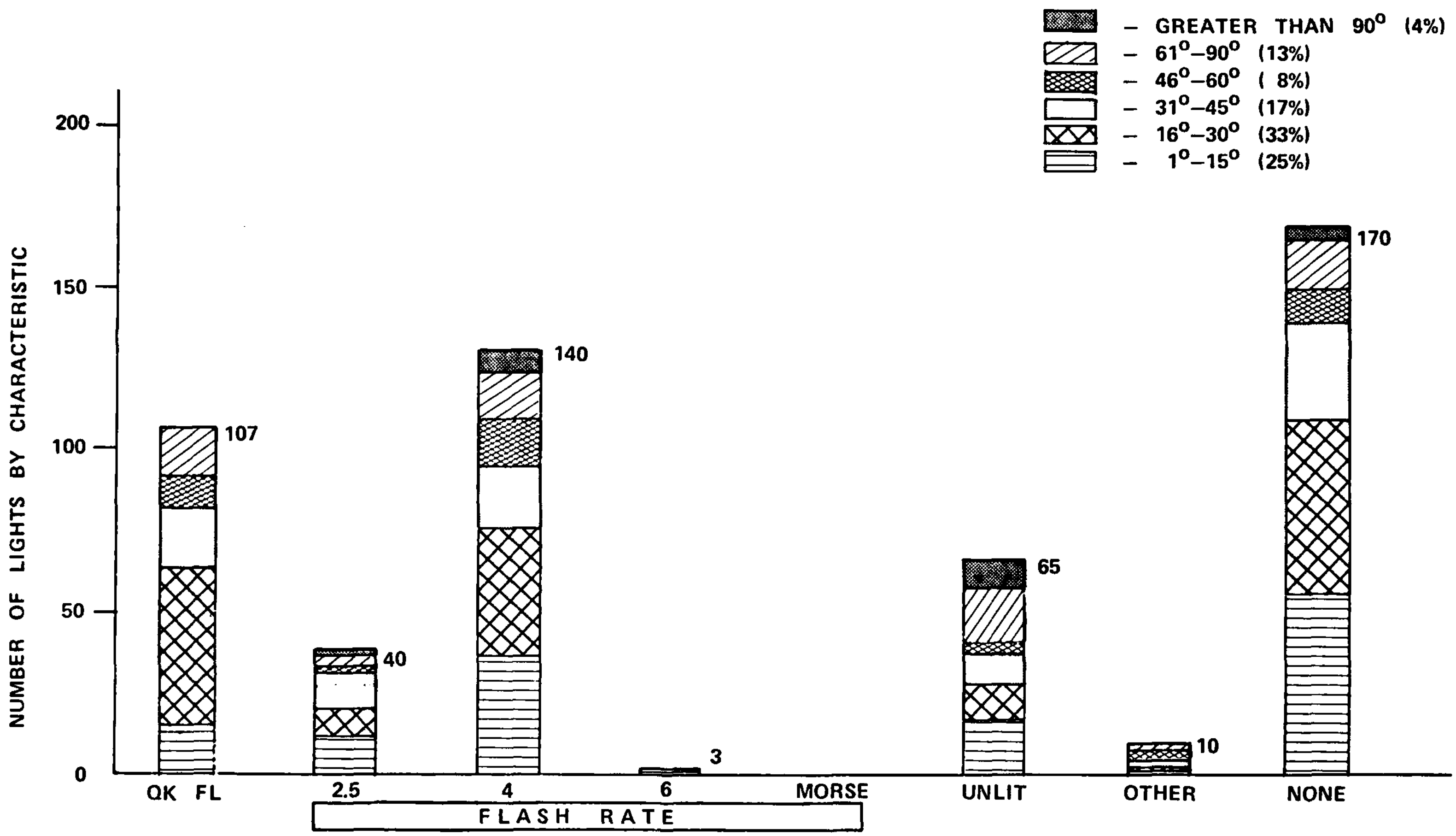

Figure 5-4. Distribution of Lights on Turns
By Occurrence and Angle

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